

## HIGH RESOLUTION, HIGH FRAME RATE VIDEO TECHNOLOGY DEVELOPMENT PLAN AND THE NEAR-TERM SYSTEM CONCEPTUAL DESIGN

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### BACKGROUND

The objective of the High Resolution, High Frame Rate Video Technology (HHVT) development effort is to provide technology advancements to remove constraints on the amount of high speed, detailed optical data recorded and transmitted for microgravity science and applications experiments. These advancements will enable the development of video systems capable of high resolution, high frame rate video data recording, processing, and transmission.

The HHVT users' requirements and near-term technology capabilities have been assessed through surveys conducted by NASA Lewis Research Center Space Experiments Division from December 1986 through December 1987. These preliminary surveys were designed to form a database to aid in defining the initial direction of the HHVT development effort. The detailed results of these surveys are presented elsewhere in this conference paper.

In summary, the users' requirements survey showed a very wide range of requirements for resolution, frame rates, and other parameters, many of which are well beyond the capability of today's technology and that of the foreseeable future. The technology survey showed that most of the available image sensors offer maximum pixel scan rates in the range of 5 to 15 Mpixels/sec/channel, while the fastest data storage medium (dynamic RAM) can record at 20 Mbyte/sec/8-bit channel. The largest data storage capacities can be achieved with magnetic tape or optical disk, but at the expense of data transfer rate. The large disparity that exists between the users' requirements and the near-term technology capability makes it obvious that for the foreseeable future, HHVT system performance will be driven by the technology capability rather than by the user's requirements.

Three techniques have been identified which will allow efficient use of the currently available technology

- (A) Simultaneous multichannel image scan and parallel channel data transfer
- (B) Video parameter tradeoff
- (C) Use of dual recording media

### (A) Simultaneous Multichannel Image Scan and Parallel Channel Data Transfer

The use of simultaneous multichannel image scan (Fig. 1) and parallel channel data transfer allows potentially very high pixel scan rates to be achieved compared to single channel scan (Fig. 2). This is true since the total pixel scan rate is directly proportional to the number of parallel channels. However, this approach has several disadvantages:

- (1) Each channel requires a separate video amplifier and A/D converter
- (2) The channels must be closely matched, that is, in sensitivity and gamma, to avoid striped shading in the displayed image
- (3) Multiple coaxial cables or fiber optic paths are required to connect the camera to the central processing unit
- (4) Circuit complexity is increased in proportion to the number of parallel channels
- (5) Data word length is proportional to the number of parallel channels

In view of the advantages and disadvantages cited above, an eight channel parallel configuration appears to be a reasonable compromise between speed and front-end complexity. At 10 Mpixels/sec/channel, the resulting scan rate will be 80 Mpixels/sec.

#### (B) Video Parameter Tradeoff

More effective use of the 80-Mpixels/sec scan rate can be achieved by trading off video parameters. For example, resolution (pixels/frame) may be traded off to obtain a higher frame rate, as shown below:

$$\frac{80 \text{ Mpixels/sec}}{1024 \times 1024 \text{ pixels/frame}} = 76.29 \text{ frames/sec}$$

$$\frac{80 \text{ Mpixels/sec}}{64 \times 64 \text{ pixels/frame}} = 19 \text{ 531 frames/sec}$$

Similarly, gray scale (bits/pixel) may be traded off to reduce the data storage required per frame, or to increase the frame rate and/or pixels/frame when the system is not sensor pixel rate limited. The use of video parameter tradeoff allows higher resolution or higher frame rate to be achieved, but not both simultaneously.

When trading off resolution (pixels/frame) one of two approaches may be used to reduce the resolution. These are illustrated in Figure 3. The first (A) increases the pixel size, while maintaining a constant scanned area at the sensor target. The second approach (B) maintains constant pixel size, but scans a reduced area or a subframe. Subframing (see Fig. 4) is best implemented in an addressable pixel array and offers the following advantages:

- (1) Pixel-per-frame usage is efficient since the size and shape of the subframe may be adjusted to cover only the area(s) of interest within the full image sensor field of view.
- (2) In an addressable array, the spatial accuracy of the transmitted image is based on the relatively high full frame resolution of the sensor, not the subframe resolution.
- (3) The pixel scan rate (pixels/sec) can be held constant while the system is operating at various subframe sizes and frame rates. This is advantageous for tube-type image pickup devices since the beam scanning

velocity and the resulting device readout sensitivity would be constant. Also, the required beam current would be constant.

#### (C) Dual Recording Media

The use of dual recording media (i.e., dynamic RAM together with a large capacity magnetic tape recorder) allows the achievement of both high data acquisition rate and large volume data storage. Here, video imagery can be captured in dynamic RAM at a very high rate and then transferred to magnetic tape at a lower rate. The process can be repeated until the mag tape is filled to capacity. The relatively small storage capacity of the dynamic RAM limits the amount of video that can be recorded per run.

#### TECHNOLOGY DEVELOPMENT PLAN

The approach for accomplishing the objective of the HHVT development effort has two parallel development thrusts consisting of a long range component/system technology development effort and a shorter range development effort focused on delivering a state-of-the-art system capability. The shorter range effort will take advantage of commercially available components/systems and the capabilities of those components/systems expected to emerge from the laboratory over the next few years. The LeRC ATD project schedule covering the HHVT activities through CY 1991 is shown in Figure 5.

#### (A) Short Range Development Effort

The objective of the HHVT short range development effort is to develop a prototype video system which will take maximum advantage of the limited near-term technology. This will be implemented as an HHVT system designed to enable the tradeoff of video parameters in a single, advanced, flexible, digital video system, so that full advantage can be taken of today's limited pixel scan rates, data transfer rates, and data storage capacity. The short range development effort will be divided into two phases.

For Phase I (based on 1988 technology), a laboratory demonstration breadboard system will be developed which can be upgraded as the technology advances. The breadboard system will be a monochrome, digital video system which will serve as the foundation upon which future HHVT technology can be developed. It will be used as a learning tool and will provide an opportunity to design, develop, and gain experience with the basic techniques and building blocks needed for an advanced HHVT video system.

The following capabilities will be developed and integrated into the breadboard system:

- (1) Technology to record and reproduce high resolution, high frame rate video images in dynamic RAM (128 Mbyte) and 1/2-in. rotary head magnetic tape (4-Mbyte/sec, 5.2-Gbyte capacity)
- (2) Technology to provide system flexibility (i.e., the ability to trade off frame rate, pixels per frame, and gray scale resolution)
- (3) Subframing capability

- (4) A high resolution pixel addressable camera. For Phase I, this will be implemented as a modified plumbicon tube camera with  $1024 \times 1024$  pixels, and a 40 Mpixel/sec scan rate
- (5) A universal digital video data acquisition, storage, and transmission format
- (6) Ancillary experiment data and video system control information recorded with each frame
- (7) Remote control of video system via digital commands
- (8) Pretrigger on external event

The Phase II effort (based on 1989-1990 technology) will consist of upgrading the Phase I system as follows:

- (1) Replacing the Phase I camera with a high resolution ( $1024 \times 1024$  pixel), 8 parallel channel, solid state, addressable pixel sensor and camera head
- (2) Doubling the pixel scan rate to 80 Mpixels/sec
- (3) Quadrupling the dynamic RAM capacity to 512 Mbytes
- (4) Adding a magnetic tape recorder/reproducer built to MIL-STD-2179 (30-Mbyte/sec transfer rate, 99-Gbyte capacity)

#### (B) Long Range Development Effort

The long range development effort will provide the critical components needed to upgrade the near-term systems, and will provide technology advancements needed for future higher performance, advanced video systems. As presently planned, the long range advanced technology development effort will initially address the following:

- (1) Design and development of a solid state, addressable pixel sensor and camera head for Phase II of the short range development effort and beyond. (This effort will start as soon as possible after the HHVT Workshop.)
- (2) Design of a pixel addressable color (or multichannel spectrally selective) camera using three solid state sensors, each with interchangeable filters
- (3) Fiber optics to link the camera head to the central processing unit
- (4) Data compression (This effort is already underway.)
- (5) Automatic subframe tracking, where the subframe automatically tracks a moving object within the field of view of the sensor.

## PROPOSED NEAR-TERM SYSTEM

The hardware built as a result of the short range development effort Phases I and II are called "Phase I Near-Term System" and "Phase II Near-Term System" respectively. A basic block diagram of a flight oriented HHVT video system with dual recording media and downlinking capability is shown in Figure 6. This represents the basic configuration of the proposed near-term HHVT systems.

### (A) Phase I Near-Term System

Figure 7 shows the Phase I Near-Term System block diagram. This configuration will be implemented initially as the breadboard system. The video signal from the camera head is digitized and demultiplexed into eight digital channels, 8 bits each, with sync and ancillary data interleaved with the video. The composite data is then parallel transferred via the 64-bit high speed video data bus to the 128-Mbyte high speed RAM or the digital magnetic tape. Data transfers between runs are made from RAM to magnetic tape via the high speed data bus and the video data MUX.

The VME bus is used to transmit control commands to the subsystems, to transmit ancillary data to the high speed video interface for insertion into the video data stream, and to transfer low rate video from RAM or mag tape to the communications interface for downlinking. The video system can be remotely controlled via uplink commands or commands from the payload specialist console. The camera control commands are shown in Table 1. The ancillary data to be stored with each frame is shown in Table 2.

### Plumbicon Camera

The breadboard system camera head uses a 1.5 in. electrostatic deflection plumbicon tube as the image sensor. The electrostatic plumbicon tube was selected for the breadboard system because it is readily available, has sufficient MTF (60%) at  $1024 \times 1024$  pixels, can scan at 40 Mpixels/sec, and can be operated in a pixel addressable mode. An addressable solid state sensor with sufficient resolution and scanning speed is not presently available and would have to be developed.

The plumbicon camera head will be used as a development tool and is planned to be used only with the breadboard system to permit the development and checkout of the other HHVT system components. A separate solid state sensor/camera development effort will be started early so that a suitable solid state camera will be available for Phase II and ultimately a flight HHVT video system.

The plumbicon is also relatively immune to raster burn. This would normally be a problem with other pickup tubes when returning to full scan after operating in a subframe mode for an extended period of time.

It is proposed that the plumbicon camera optics consist of the following:

- (1) Interchangeable Objective Lens (F mount 35-mm camera format)
- (2) Removable 40 mm MCP gated intensifier (40 mm image diagonal) with a relay lens (1.43 image reduction ratio)

A digitally controlled pixel addressable electrostatic deflection system is shown in Figure 8. The subframe start and stop coordinates are loaded from the VME bus into the control registers. An external frame start trigger pulse initiates the scanning of each frame.

The horizontal sweep sawtooth waveform is obtained from a D/A converter which is driven by a binary counter. The counter is advanced one count on each pixel clock cycle. Retrace occurs when the count equals the binary number stored in the "horizontal stop address" control register. The horizontal starting position of each line is controlled by the binary number stored in the "horizontal start address" which is used to preset the counter. The vertical scan circuitry operates in a similar manner. The vertical binary counter is advanced one count during each horizontal retrace interval.

### Video Image Acquisition Cycle

Figure 9 shows the video image acquisition cycle concept which is a unique design feature of the HHVT near-term system. One frame is scanned per acquisition cycle. Each cycle or frame is initiated by a trigger pulse from the frame rate pulse generator (see Fig. 7).

The frame rate pulse generator is essentially a programmable frequency divider clocked by the crystal controlled pixel clock. The frequency divider ratio, and hence the frame rate, is remotely controlled. The principal advantage of the triggered acquisition cycle approach is that the frame rate can be very precisely set to a wide range of convenient values such as a 100, 200, 500, 1000, 2000, 5000, etc. frames/sec. This is very desirable when the HHVT video system is used for motion analysis.

### Pretrigger on External Event

The use of RAM as a video storage medium permits the video system to be operated in a standby recording mode where the "first in" video data stored in RAM is continuously overwritten with current video data. When the external trigger event occurs, the recording process is continued for a predetermined number of frames and then is stopped. Contained in RAM is a continuous sequence of video frames representing time before, during, and after the trigger event.

This mode of operation is useful when attempting to capture image sequences of unpredictable and sporadically occurring experimental phenomena. The images can be recorded without consuming enormous amounts of video data storage while waiting for the event to occur.

### (B) Phase II Near-Term System

Figure 10 shows a block diagram of the Phase II near-term system. This is essentially the Phase I system upgraded with a new camera containing an eight channel custom 1024 x 1024 pixel solid state image sensor. The upgrade also includes more dynamic RAM and the MIL-STD-2179 mag tape recorder with its higher data transfer rate and larger storage capacity. The upgraded system has eight parallel video channels from the sensor all the way through to the 64-bit high speed data bus. The Phase II system scan rate will be at least 80 Mpixels/sec.

The proposed Phase II system physically will consist of four packages to house the components shown in Figure 10.

1. Camera head (dimensions to be determined)
2. Chassis (19 in. wide by 14 in. high by 25 in. deep)
3. VME bus chassis (19 in wide by 14 in. high by 25 in. deep) containing the following:
  - A. VME BUS backplane
  - B. System controller boards (CPU, RAM, ROM)
  - C. Mag tape controller board
  - D. Data acquisition and ancillary information encoder boards
  - E. Communications interface board
4. MIL-STD-2179 mag tape recorder (16 in. wide by 17 in. high by 16 in. deep) with record/reproduce electronics

Figure 11 shows the pixel layout of the solid state image sensor with its eight parallel channels and the  $8 \times 8$  pixel addressable blocks.

#### Theoretical Performance of the Phase I and II Near-Term Systems

Tables 3 to 6 show the theoretical performance of the Phase I and Phase II systems at various subframe sizes and gray scale levels when recording in dynamic RAM and magnetic tape. The resulting frame rates do not include the effects of the horizontal and vertical retrace blanking intervals. The actual frame rates will be somewhat lower. The increased frame rate and the increased total frame storage capacity which result when pixels per frame are traded off are readily apparent. Trading off gray scale increases the frame storage capacity. However, trading off gray scale will not increase the frame rate once the maximum sensor pixel scan rate is reached.

Figures 12 to 15 show how the Phase I and Phase II system performance compares to the users' requirements on a data acquisition rate basis and on a data storage capacity basis. The performance of each system (i.e., data acquisition rate in Mbyte/sec or data storage capacity in Mbytes or Gbytes) is represented by a diagonal line superimposed on the users' requirements. In general, the users' requirements represented by points below and to the left of the diagonal line can be met by that system. One byte/pixel is assumed for these comparisons.

#### Sync and Ancillary Data

When scanning and digitizing an image to generate video data, sync information must be periodically inserted in the data stream so that the image can be later reconstructed. For scientific video imagery it is also desirable to periodically insert other ancillary data. See Table 2.

The designer has the choice of inserting the sync and ancillary (S&A) data between each full video frame or placing the S&A data within the video frame where some of the pixel space is occupied by S&A data. There are two advantages to placing the S&A data within the frame.

1. Each frame together with its S&A data always occupies memory in blocks where the number of bits per block is an integral power of two. Such data blocks stack up neatly in disk and tape data storage. For example, a  $256 \times 256$  pixel frame at 4 bits/pixel with S&A data within the video frame occupies 32 768 bytes or exactly 64 disk sectors at 512 bytes/sector. If the 512 S&A data bits are inserted between frames, each frame with S&A data occupies a total of 32 832 bytes or 64.125 disk sectors.
2. With S&A data within the frame, the sync data can be further divided into frame sync and line sync. The use of line sync results in faster initial synchronization and faster resynchronization in the event of momentary transmission loss or sync data errors.

It is recommended that the near-term HHVT systems be designed to place the S&A data within each frame as shown in Figure 16. Each frame starts with a 16 bit frame sync word, followed by a 16 bit line sync word occurring at the beginning of each group of eight lines. The ancillary data (384 bits total) consists of eight groups of 48 bits interleaved among the first eight sync words (one frame sync plus seven line sync words). The frame sync word is shown shaded.

The picture information lost due to the S&A data contained within a  $64 \times 64 \times 1$  frame ( $64 \times 64$  pixels, 1 bit/pixel) is illustrated in Figure 16. In this frame the S&A data occupies 512 bits. Figure 17 shows the lost picture information in a  $128 \times 128 \times 1$  frame. Note that when the pixels per frame is quadrupled the lost picture area is effectively cut in half. As the bits/pixel is increased, the number of lost pixels will proportionately decrease. The vertical column at the left containing the S&A data is blanked off on the displayed image. For the  $128 \times 128 \times 1$  frame the actual displayed picture area is  $120 \times 128$  pixels.

In playing back a sequence of frames, it is envisioned that once the composite video data is received and stored on disk or magnetic tape, the display processing software will look for three or more consecutive line sync words by means of a repetitive sync window. The line sync words are interleaved with the video data at a known spacing or repetitive pattern where the spacing depends on the specific pixels/frame and bits/pixel. Once the software locks onto the line sync repetition pattern, it will step through the line sync words and eventually find the next frame sync word. In essence, the line sync leads the system to find the frame sync. Once the frame sync word is found, synchronization has been achieved.

It is necessary that the system look for a repetitive sync pattern before attempting to synchronize, since the sync words are not unique from the video data. It is possible from time to time to have consecutive pixels form the same 16 bit word as the line or frame sync word. Looking through a sync window for a repetitive sync pattern and locking onto the pattern makes the system immune to these spurious sync words.

#### Video Data Format

Figure 18 is a graphic representation of the high speed video RAM. Shown on the left are the 64 parallel data bits from the high speed video data bus.



These are divided into eight video channels at eight bits per channel. The data is sequentially clocked into RAM in 64 bit parallel words starting at address 0000000.

Figure 19 shows how the video, sync, and ancillary data will appear in RAM for the Phase II system. With the data organized in this way, the S&A data will occupy the left edge of the video frame as shown in Figures 16 and 17. In Figure 19, the first 64-bit word (address 0000000) contains the frame sync (16 bits) and 48 bits of ancillary data. The next seven 64-bit words contain the first eight lines of video data. Next is the first line sync (16 bits) and 48 more bits of ancillary data, followed by seven 64-bit words of video for lines 9 through 16, and so on.

This is a flexible format that can accommodate various pixels/frame (needed for subframing) and various gray scale resolutions (bits/pixel). Increasing either simply increases the amount of video data placed between the 64-bit S&A words. In Figure 19 the spacing between the S&A words will increase, as will the total number of 64-bit video data words required per frame.

The memory allocation for each of the eight parallel channels as a function of bits/pixel is shown graphically at the bottom of Figure 19. Each of the four blocks represents the first line (64 pixels) of the raster shown in Figure 16. The first eight bits (shown shaded) of each block are part of the 16-bit frame sync word. Note that the pixels are numbered in Figures 16 and 19.

Figure 20 shows graphically the data organization in RAM for the Phase I system. This organization is different from the Phase II system data organization since the plumbicon is a single channel device. This organization is required so that the S&A data will occupy the left edge of the video frame as shown in Figures 15 and 16.

The plumbicon's single video output, unlike the eight channel solid state sensor, is demultiplexed sequentially to the eight digital channels. The result is that each scan line is distributed among the eight channels. The S&A data is now all contained in channel 1.

The memory allocation as a function of bits/pixel is shown to the right of Figure 20. Again, each of the four blocks represents the first line (64 pixels) of the raster shown in Figure 16.

### SUMMARY

The objective of the High Resolution, High Frame Rate Video Technology (HHVT) development effort is to provide technology advancements to remove constraints on the amount of high speed, detailed optical data recorded and transmitted for microgravity science and applications experiments. These advancements will enable the development of video systems capable of high resolution, high frame rate video data recording, processing, and transmission.

The results of the initial surveys show a large disparity between the microgravity science and applications video users' requirements and the near-term technology capability. The initial objective of the HHVT development effort is to develop techniques to allow the most efficient use of the limited capability of the current and near-term technology so that we may

begin to close the gap between the users' requirements and the technology capability. Techniques such as multichannel image scan, video parameter tradeoff, and the use of dual recording media have been identified as methods of making the most efficient use of the near-term technology.

A technology development plan has been formulated which has two parallel development thrusts consisting of a long range component/system technology development effort and a shorter range effort that will take advantage of commercially available components expected to be available in the near future. The short range effort will focus on developing the techniques mentioned above to make the most efficient use of the near-term technology. Emphasis will be on system flexibility, that is, the ability to trade off resolution, frame rate, and gray scale in one system so that today's limited pixel scan rates and data transfer rates can be used to full advantage. A video data format designed to accommodate the system flexibility is discussed.

The short range effort will be divided into two phases. Phase I will be the development of a laboratory demonstration breadboard system which can be upgraded as the technology advances and will serve as the foundation upon which future HHVT technology can be developed. As currently planned, the Phase I system will incorporate a pixel addressable plumbicon tube camera.

Phase II will consist of upgrading the Phase I system with a custom pixel addressable multichannel parallel scan solid state camera and other improvements.

The long range effort will provide the critical components needed to upgrade the near-term systems and will provide the technology advancements needed for future higher performance, advanced video systems.

Table 1CAMERA CONTROL COMMANDS

<u>COMMAND</u>	<u>BITS REQUIRED</u>
SCAN START ADDRESS: (X)	7
(Y)	7
SCAN STOP ADDRESS: (X)	7
(Y)	7
PEDESTAL LEVEL:	8
VIDEO GAIN:	8
INTENSIFIER GATE TIME:	12
SENSOR INTEGRATION TIME:	12
IRIS OPEN (RATE 1,2,3):	2
IRIS CLOSE (RATE 1,2,3):	2
FOCUS IN (RATE 1,2,3):	2
FOCUS OUT (RATE 1,2,3):	2
ZOOM IN (RATE 1,2,3):	2
ZOOM OUT (RATE 1,2,3):	2
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TOTAL BITS REQUIRED:	80
TOTAL BITS PLANNED:	128 (16 BYTES)

Table 2ANCILLARY INFORMATION STORED WITH EACH FRAME

<u>PARAMETER</u>	<u>BITS REQUIRED</u>
CAMERA NO: (1 THROUGH 8)	3 (BINARY)
FRAME NO: (0 TO 1,048,576)	20 (BINARY)
TIME: DAY XXX	9 (BCD)
HR. XX	7 (BCD)
MIN XX	7 (BCD)
SEC XX.XXXX	27 (BCD)
FRAME RATE: X.XXEXX	35 (ASCII)
SUBFRAME ORIGIN: (X)	7 (BINARY)
(Y)	7 (BINARY)
SUBFRAME DIMENSIONS: (X)	7 (BINARY)
(Y)	7 (BINARY)
GRAY SCALE RESOLUTION (BITS/PIXEL):	3 (BINARY)
16 EVENT MARKERS:	16
EXPERIMENT DATA (BCD, BINARY, OR ASCII):	64
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TOTAL BITS REQUIRED:	219
TOTAL BITS AVAILABLE:	384 (48 BYTES)

Table 3

Theoretical Performance  
Phase I Near-Term HHVT Video System  
Mode: Burst Record (RAM)

Image Sensor: 1.75 in. Plumbicon Tube  
Sensor Pixel Rate: 40 Mpixel/sec  
Storage Medium: Dynamic RAM  
Max Data Transfer Rate: 40 Mbyte/sec  
Storage Capacity: 128 Mbyte  
Total Recording Time: 3.2 sec  
Reference Note: 100 ft 16 mm Film contains 4000 frames

Subframe Pixels	----- Gray Scale Levels -----			
	256	16	4	2
1024 X 1024	** * (1.22E2)	38.1 (2.44E2)	38.1 (4.88E2)	38.1 (9.77E2)
512 X 512	152.6 (4.88E2)	152.6 (9.77E2)	152.6 (1.95E3)	152.6 (3.91E3)
256 x 256	610.3 (1.95E3)	610.3 (3.91E3)	610.3 (7.81E3)	610.3 (1.56E4)
128 X 128	2441.4 (7.81E3)	2441.4 (1.56E4)	2441.4 (3.12E4)	2441.4 (6.25E4)
64 X 64	9765.6 (3.12E4)	9765.6 (6.25E4)	9765.6 (1.25E5)	9765.6 (2.50E5)

\*\* Frames/sec  
\* Total Stored Frames

Table 4

Theoretical Performance  
Phase I Near-Term HHVT Video System  
Mode: Continuous Tape Record

Image Sensor: 1.75 in. Plumbicon Tube  
Sensor Pixel Rate: 40 Mpixel/sec  
Storage Medium: 1/2 in. Magnetic Tape  
Max Data Transfer Rate: 4.0 Mbyte/sec  
Storage Capacity: 5.2 Gbyte  
Total Recording Time: 21.6 min  
Reference Note: 100 ft 16 mm Film contains 4000 frames

Subframe Pixels	----- Gray Scale Levels -----			
	256	16	4	2
1024 X 1024	** * (4.96E3)	3.8 (9.92E3)	7.6 (1.98E4)	30.5 (3.97E4)
512 X 512	15.3 (1.98E4)	30.5 (3.97E4)	61.0 (7.93E4)	122.1 (1.59E5)
256 X 256	61.0 (7.93E4)	122.1 (1.59E5)	244.1 (3.17E5)	488.3 (6.35E5)
128 X 128	244.0 (3.17E5)	488.3 (6.35E5)	976.6 (1.27E6)	1953.1 (2.54E6)
64 X 64	976.0 (1.27E6)	1953.1 (2.54E6)	3906.0 (5.08E6)	7812.5 (1.02E7)

\*\* Frames/sec  
\* Total Stored Frames

Table 5

Theoretical Performance  
Phase II Near-Term HHVT Video System  
Mode: Burst Record (RAM)

Image Sensor: 1024 x 1024 Pixel Array  
Sensor Pixel Rate: 80 Mpixel/sec  
Storage Medium: Dynamic RAM  
Max Data Transfer Rate: 80 Mbyte/sec  
Storage Capacity: 512 Mbyte  
Total Recording Time: 6.4 sec  
Reference Note: 100 ft 16 mm Film contains 4000 frames

Subframe Pixels	----- Gray Scale Levels -----			
	256	16	4	2
1024 X 1024	** * (4.88E2)	76 (9.76E2)	76 (1.95E3)	76 (3.91E3)
512 X 512	305 (1.95E3)	305 (3.91E3)	305 (7.81E3)	305 (1.56E4)
256 X 256	1220 (7.81E3)	1220 (1.56E4)	1220 (3.12E4)	1220 (6.25E4)
128 X 128	4882 (3.12E4)	4882 (6.25E4)	4882 (1.25E5)	4882 (2.50E5)
64 X 64	19531 (1.25E5)	19531 (2.50E5)	19531 (5.00E5)	19531 (1.00E6)

\*\* Frames/sec  
\* Total Stored Frames

Table 6

Theoretical Performance  
Phase II Near-Term HHVT Video System  
Mode: Continuous Tape Record

Image Sensor: 1024 x 1024 Pixel CID Array  
Sensor Pixel Rate: 80 Mpixel/sec  
Storage Medium: MIL2179AS Magnetic Tape  
Max Data Transfer Rate: 30 Mbyte/sec  
Storage Capacity: 99 Gbyte  
Total Recording Time: 55 min  
Reference Note: 100 ft 16 mm Film contains 4000 frames

Subframe Pixels	----- Gray Scale Levels -----			
	256	16	4	2
1024 X 1024	** * (9.44E4)	28 (1.89E5)	56 (3.78E5)	56 (7.55E5)
512 X 512	114 (3.78E5)	228 (7.55E5)	228 (1.51E6)	228 (3.02E6)
256 X 256	457 (1.51E6)	914 (3.02E6)	914 (6.04E6)	914 (1.21E7)
128 X 128	1831 (6.04E6)	3662 (1.21E7)	3662 (2.42E7)	3662 (4.83E7)
64 X 64	7324 (2.42E7)	14648 (4.83E7)	14648 (9.67E7)	14648 (1.93E8)

\*\* Frames/sec  
\* Total Stored Frames

Figure 1

Multi Channel Parallel Scan  
(8 Parallel Channels)

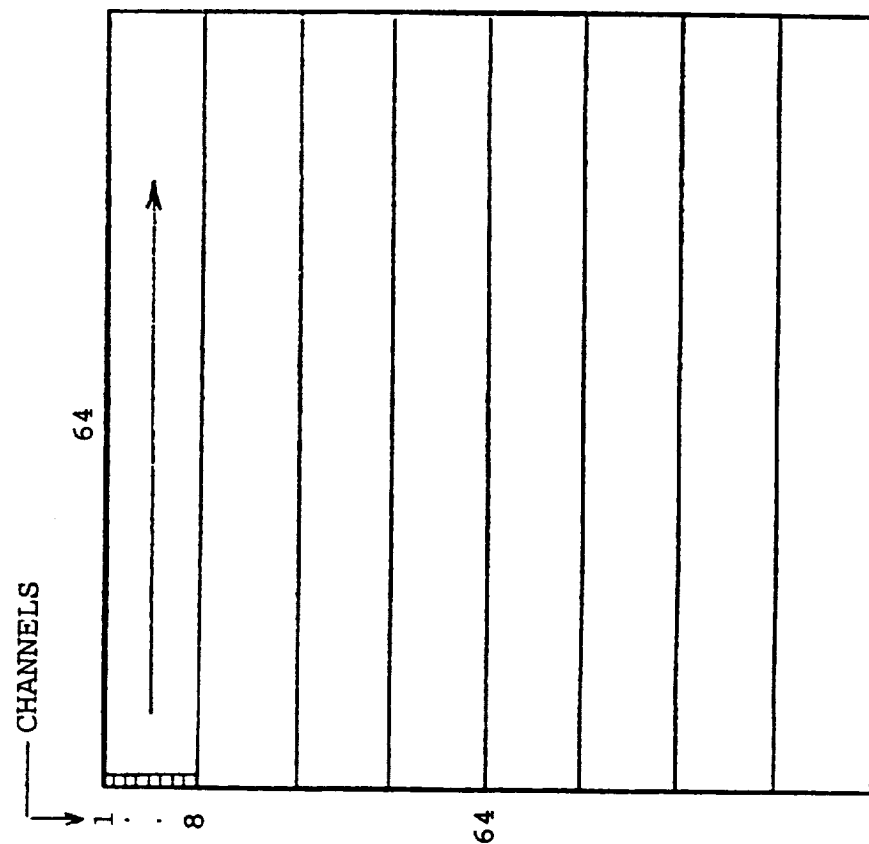


Figure 2

Single Channel Progressive Scan  
(8 Parallel Channels)

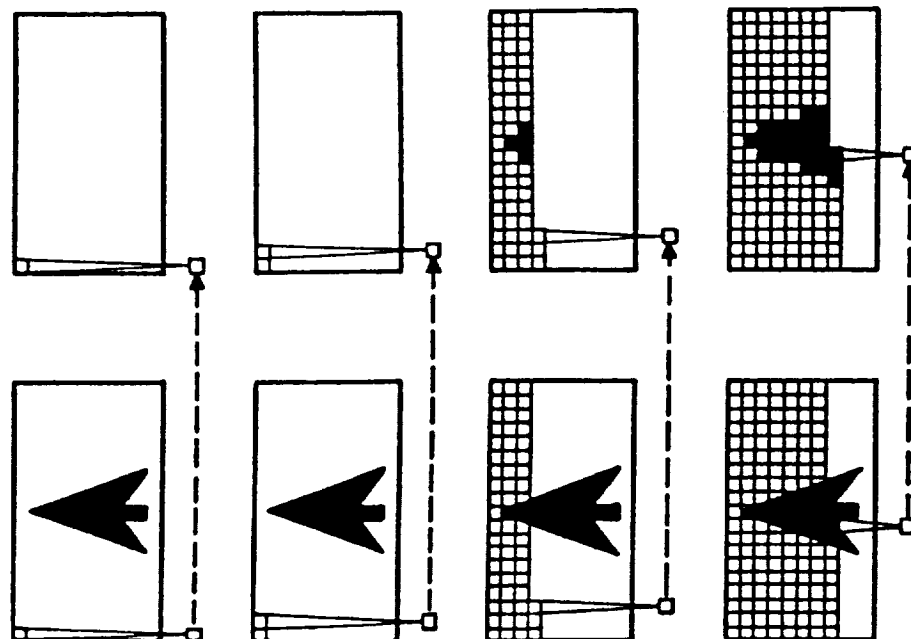


Figure 3

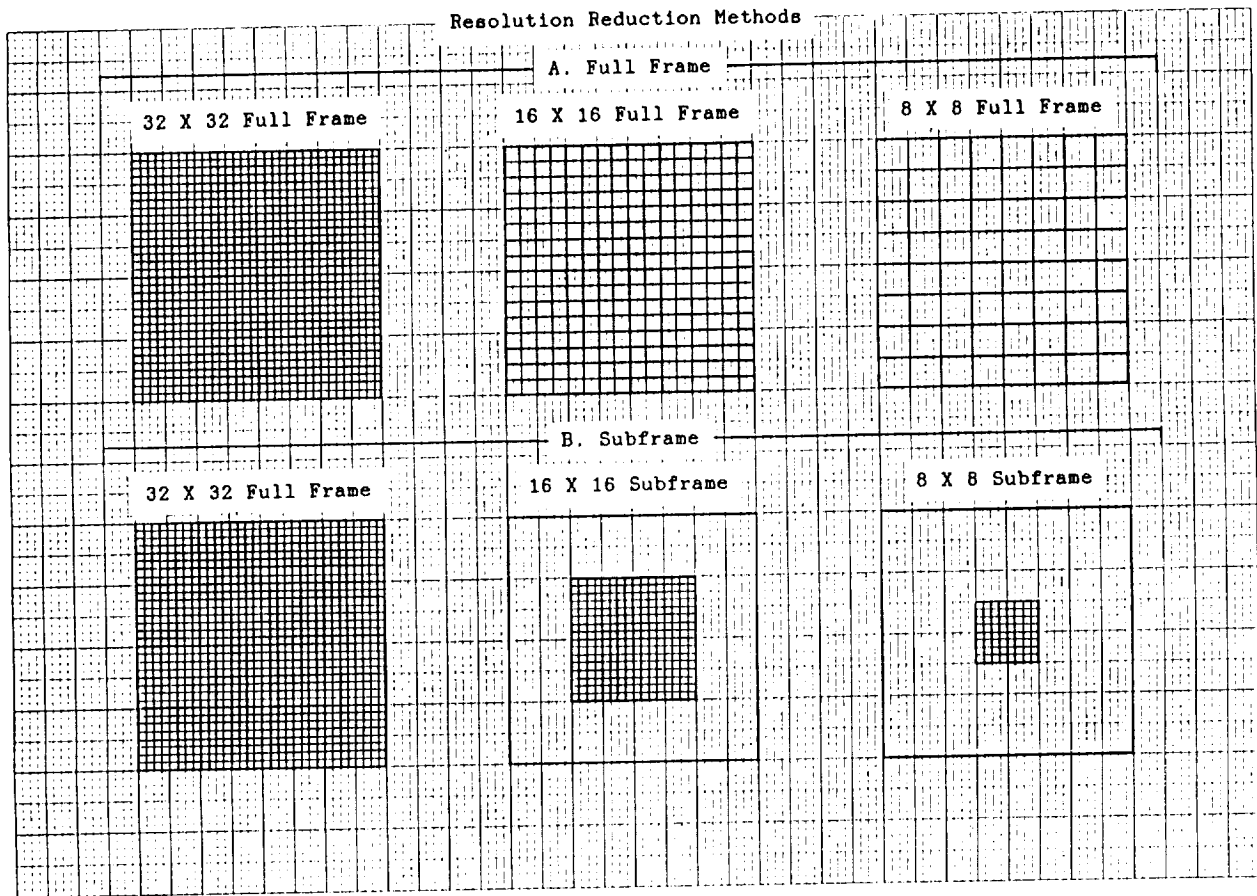
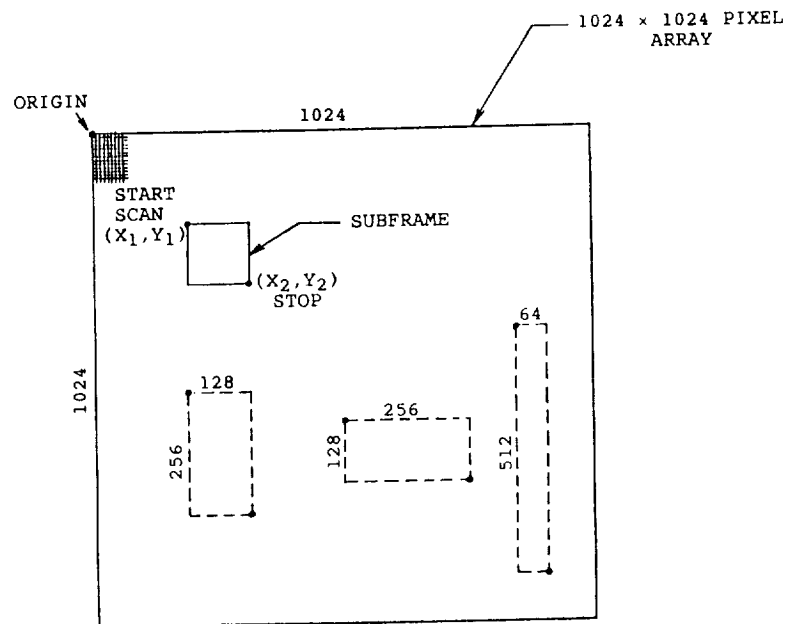


Figure 4

### Subframe Examples



NOTE: SUBFRAME COORDINATES ON 128 x 128 GRID.

Figure 5

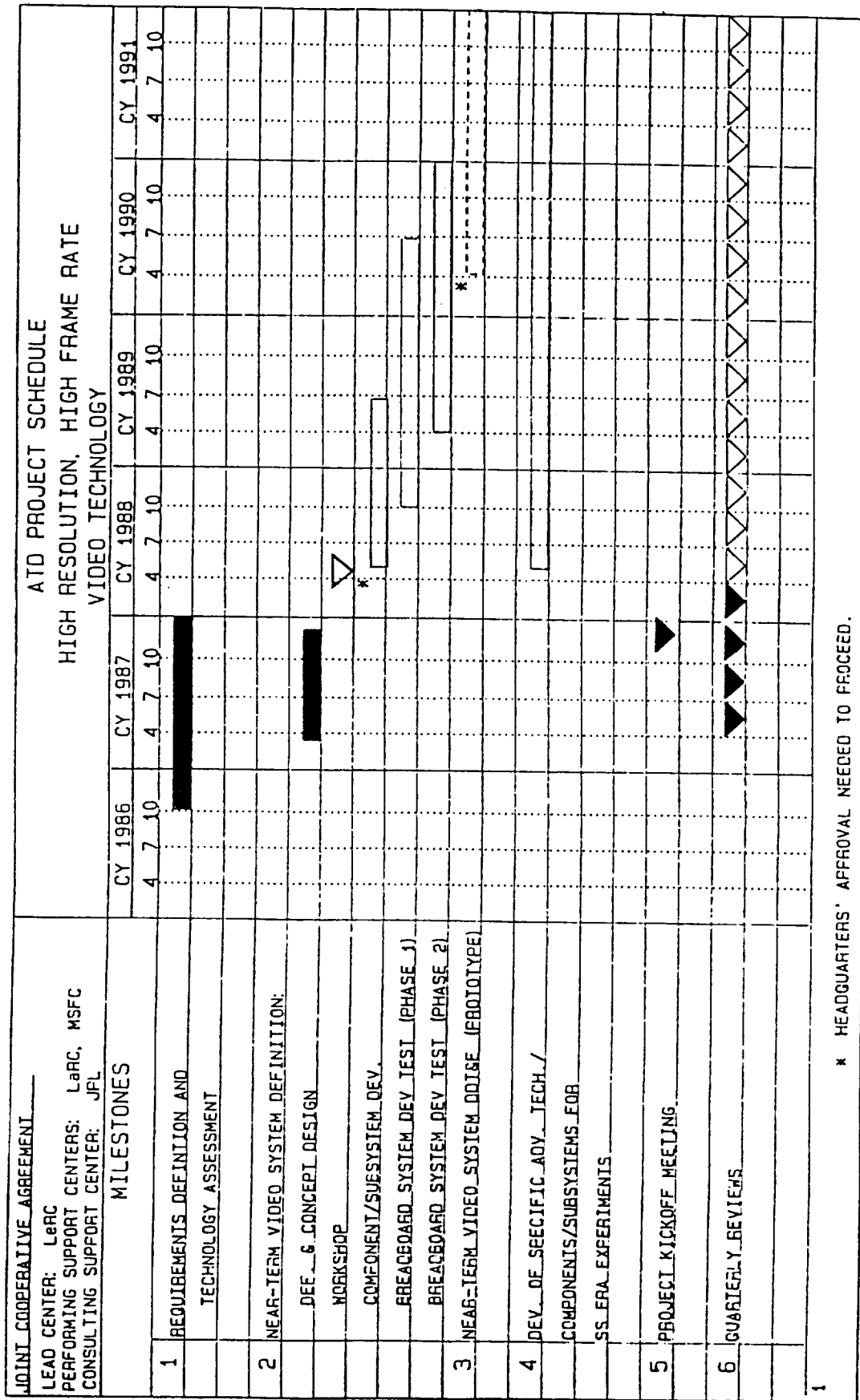




Figure 6

# HHVT Video System

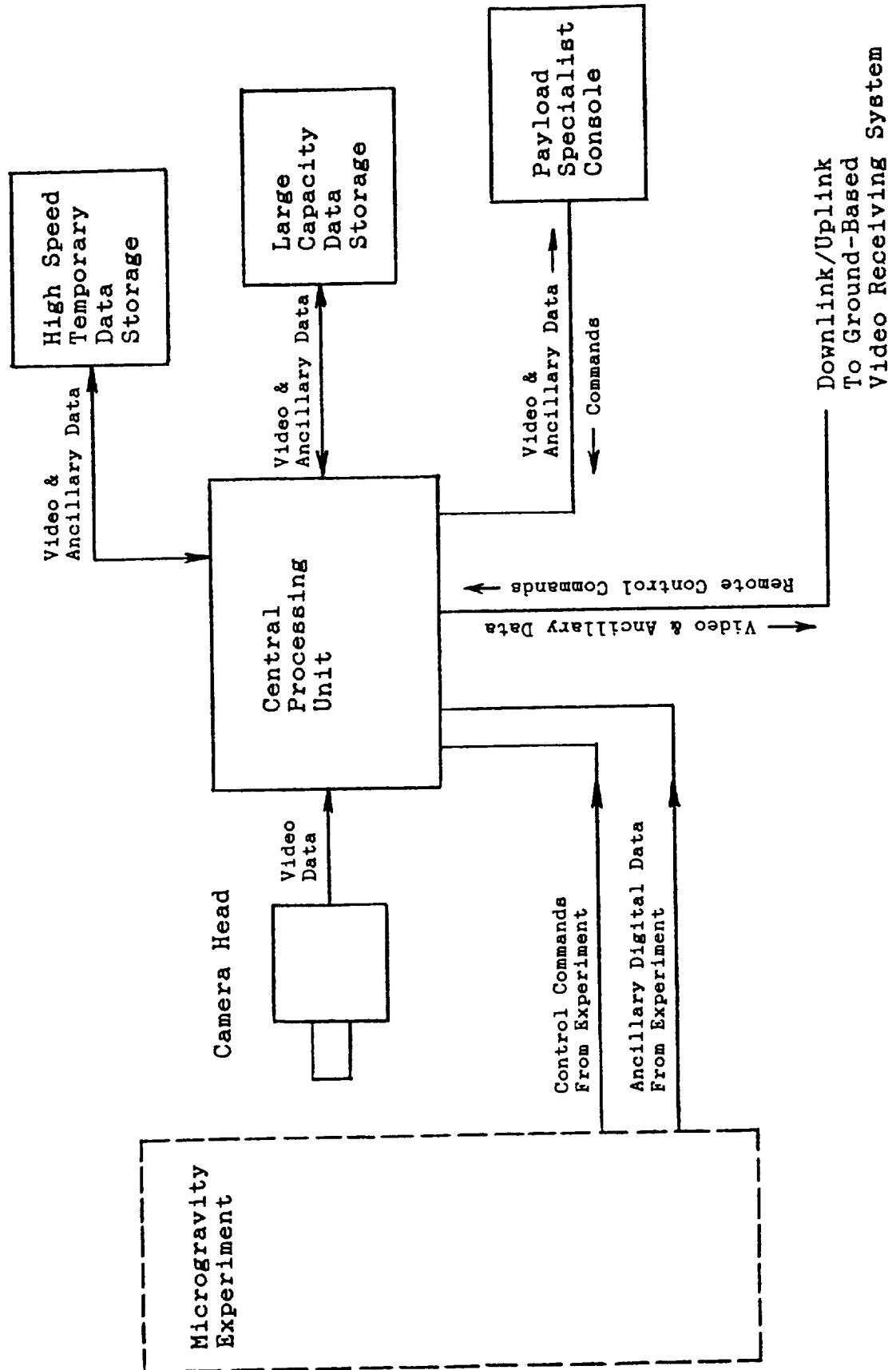


Figure 7

# Phase I Near-Term HHVT video system (Flight System Block Diagram)

R. Ziemke  
6/4/88

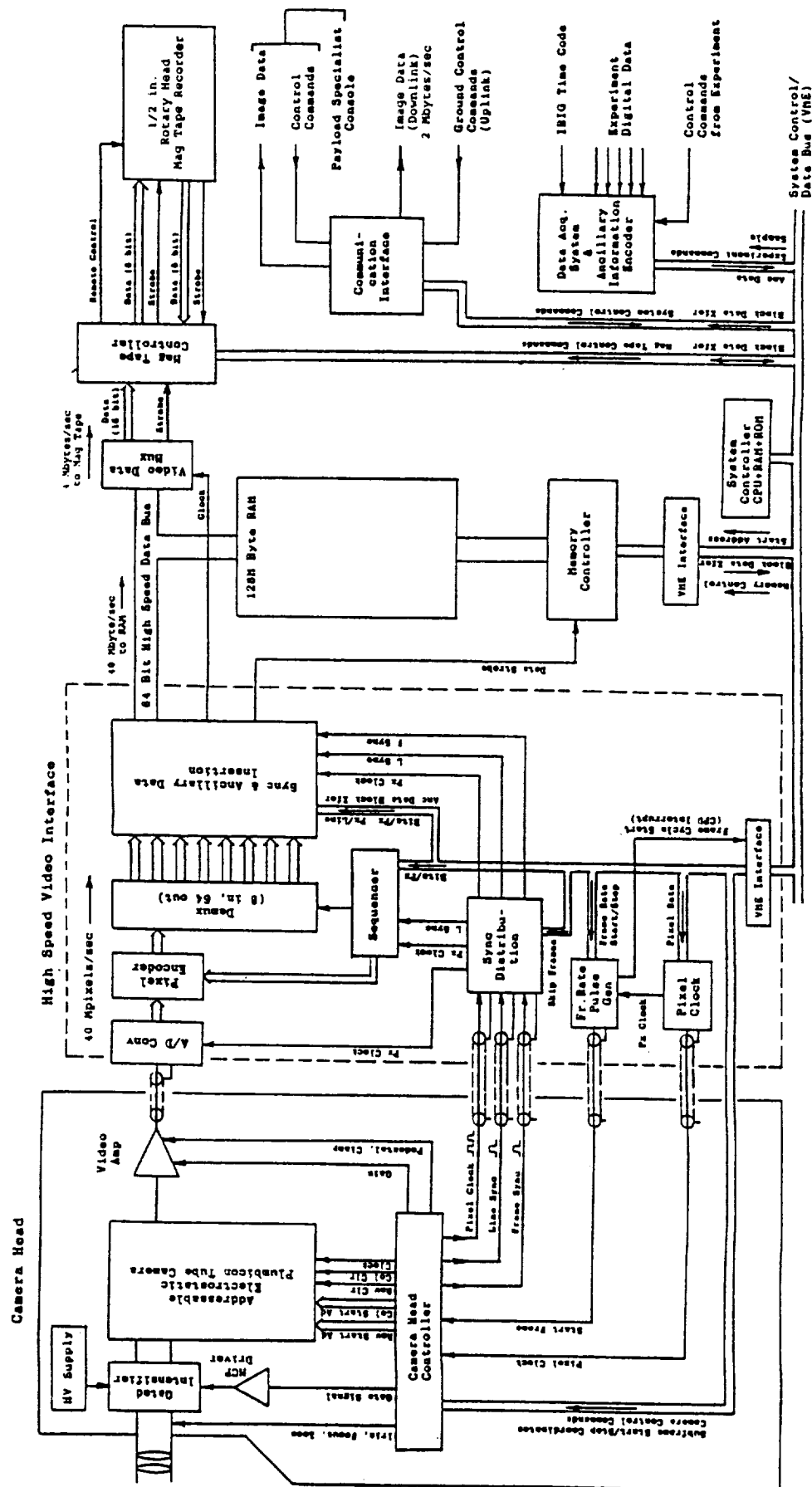


Figure 8  
Pixel Addressable Deflection Concept  
for Electrostatic Plumbicon Camera  
(8 X 8 Pixel Blocks)

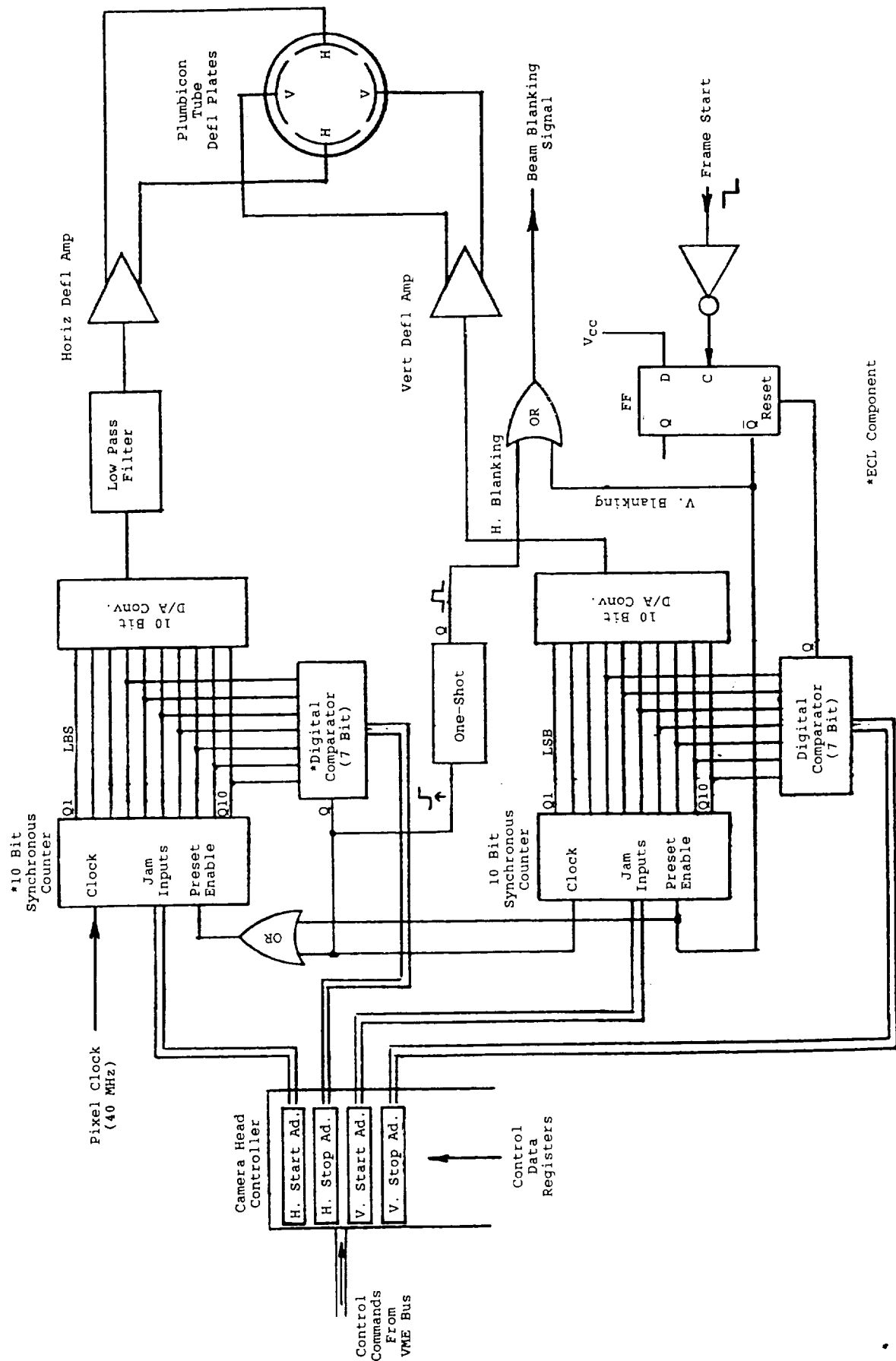


Figure 9  
Video Image Acquisition Cycle

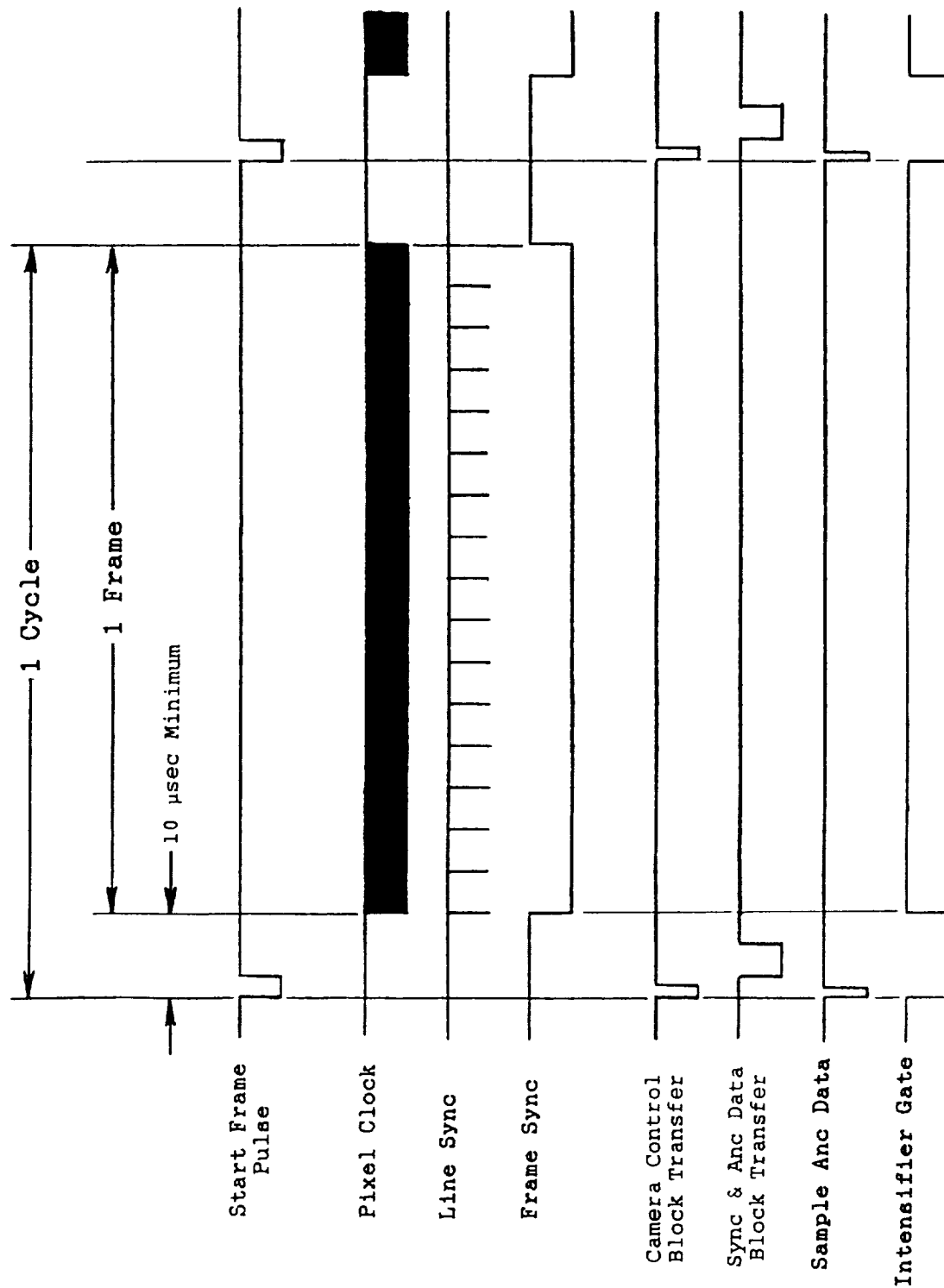


Figure 10  
Phase II Near-Term HHVT Video System  
(Flight System Block Diagram)

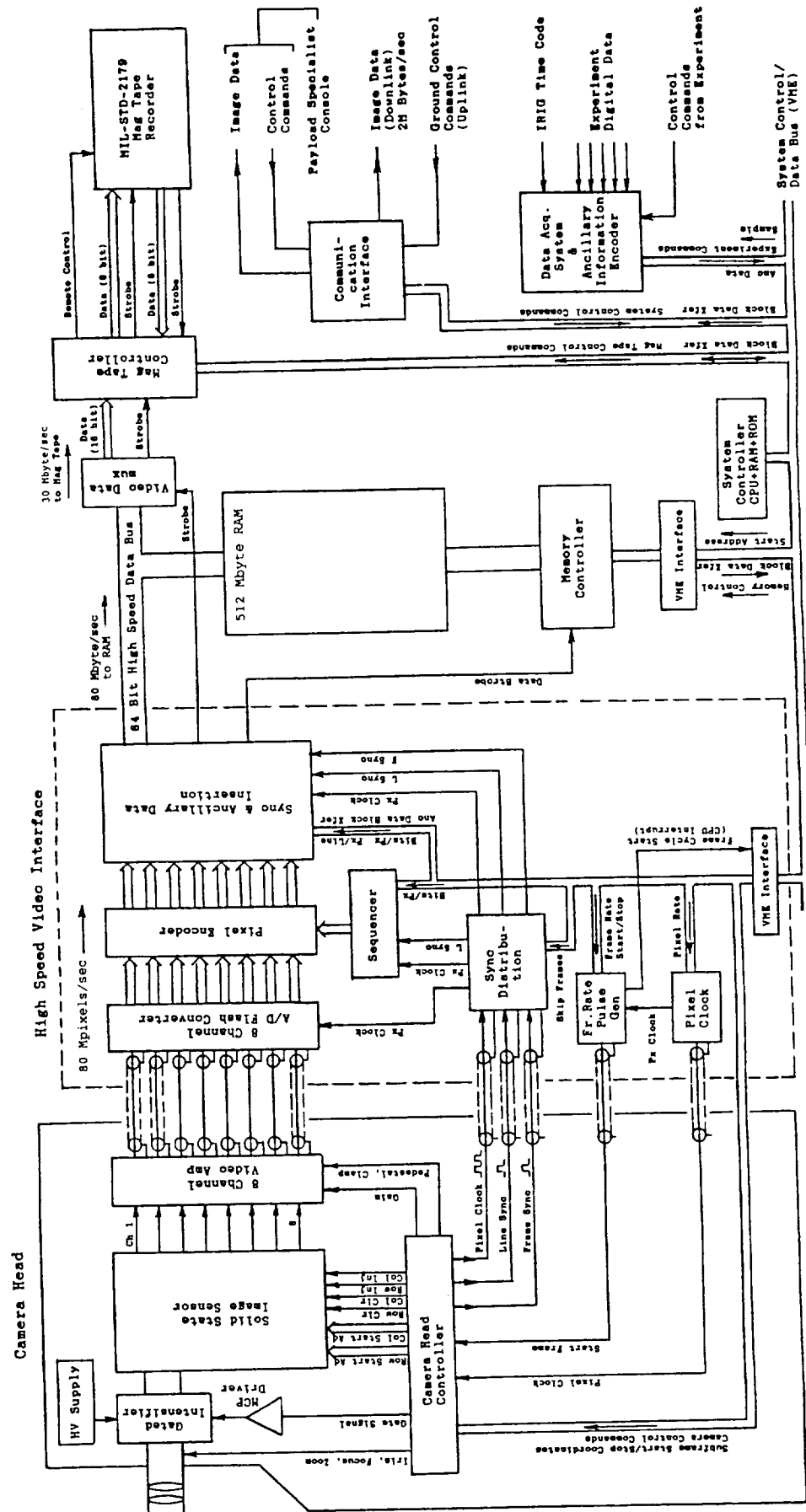


Figure 11

1024 × 1024 Addressable Solid State Image Sensor  
(Phase II Near-Term System)  
8 × 8 Pixel Addressable Blocks

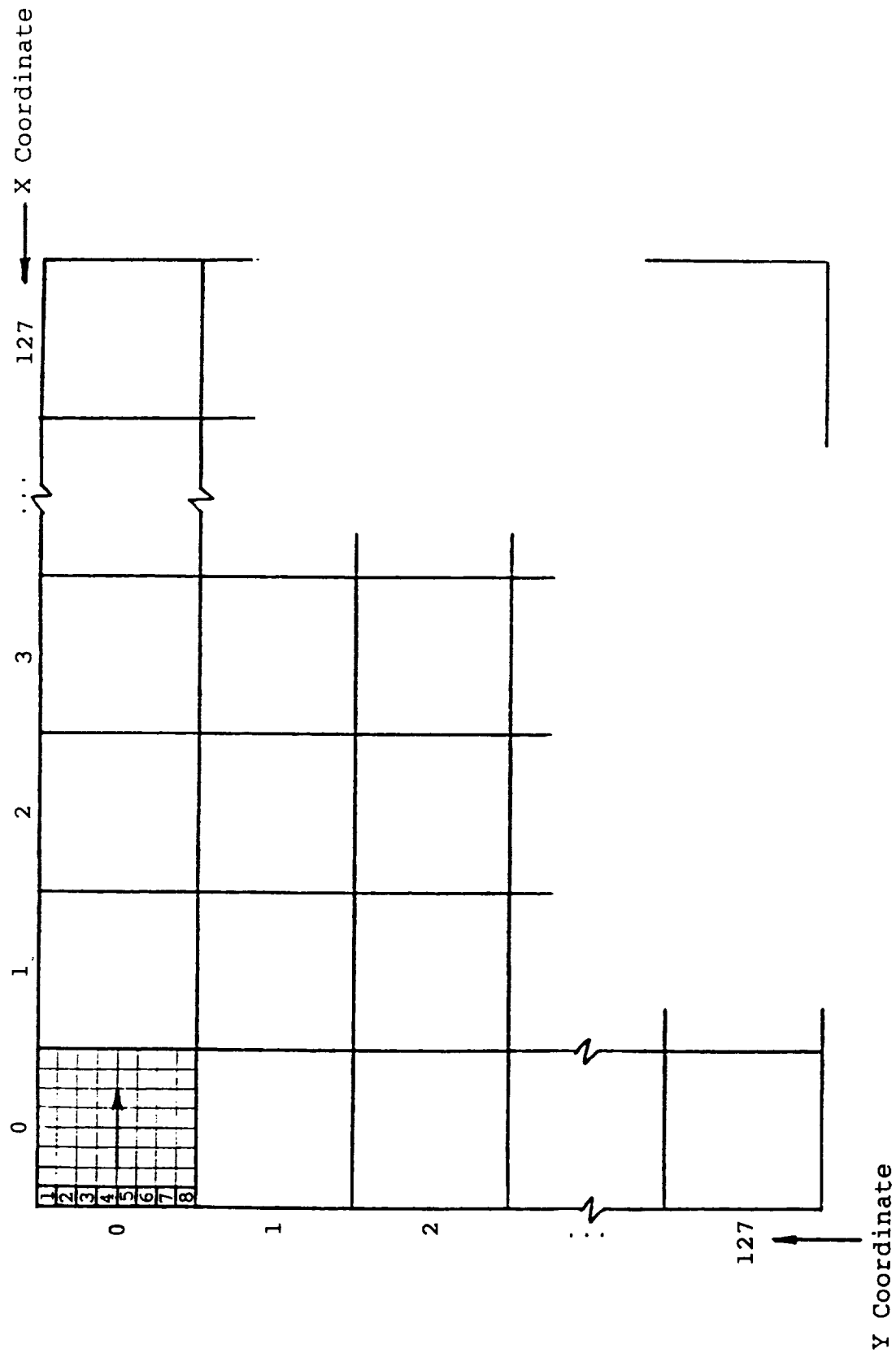
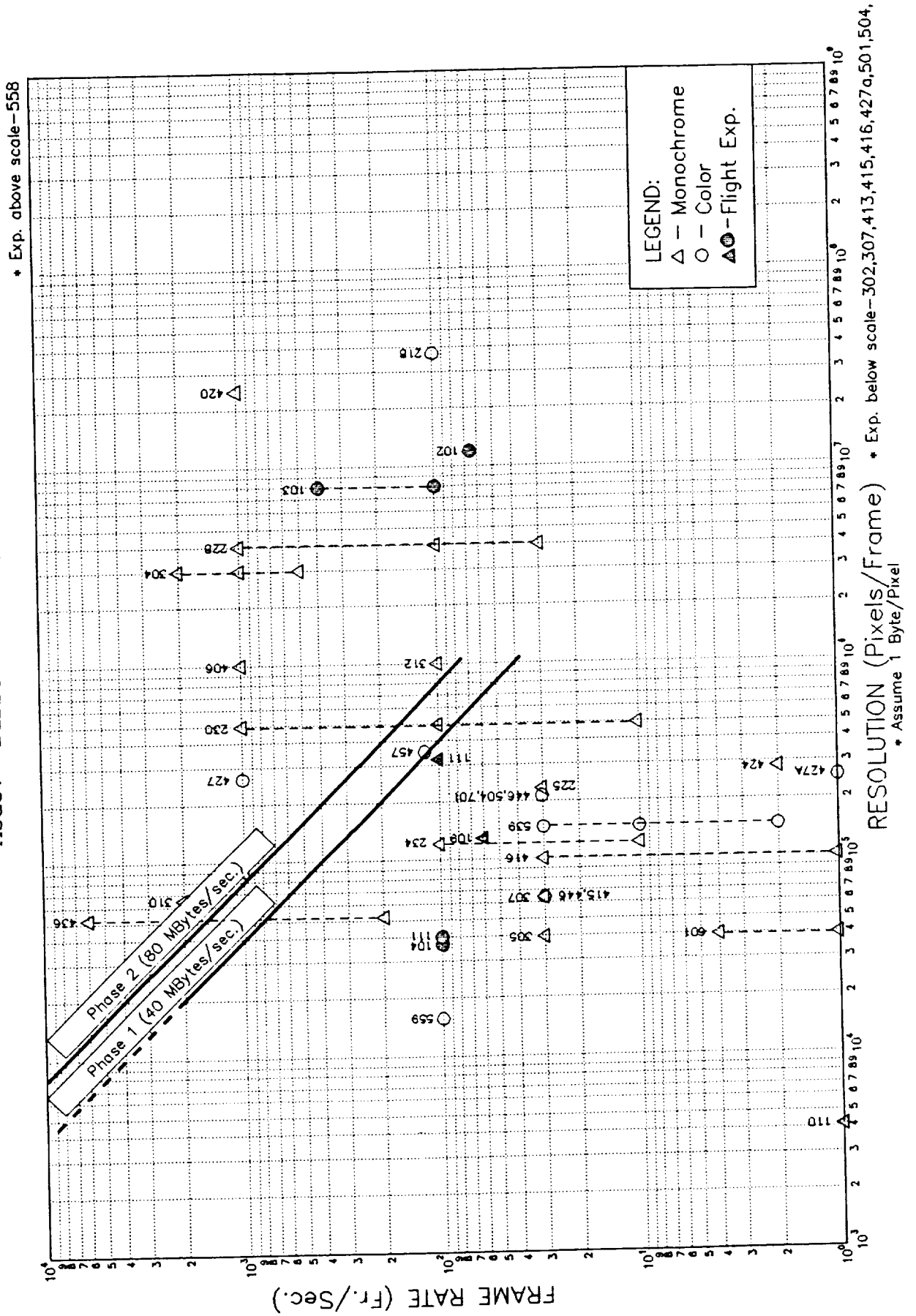


Figure 12

Near-Term System Performance  
Data Acquisition Rate vs User Requirements  
Mode: Burst Record (RAM)



Near-Term System Performance  
Data Acquisition Rate vs User Requirements  
Mode: Continuous Tape Record

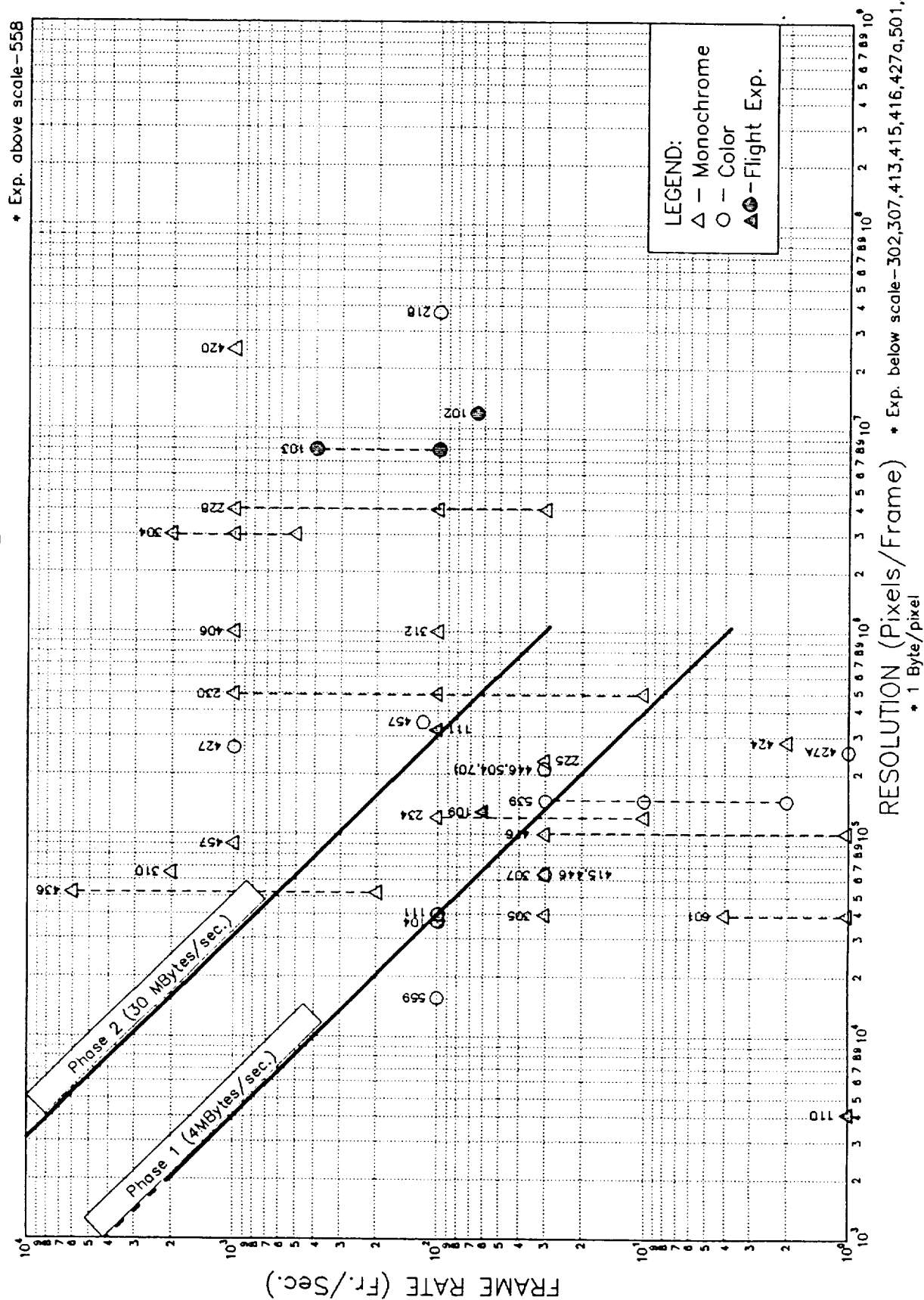




Figure 14

Near-Term System Performance  
Data Storage Capacity vs User Requirements  
Mode: Burst Record (RAM)

\* Exp. above scale-416  
- Refer to appendix A

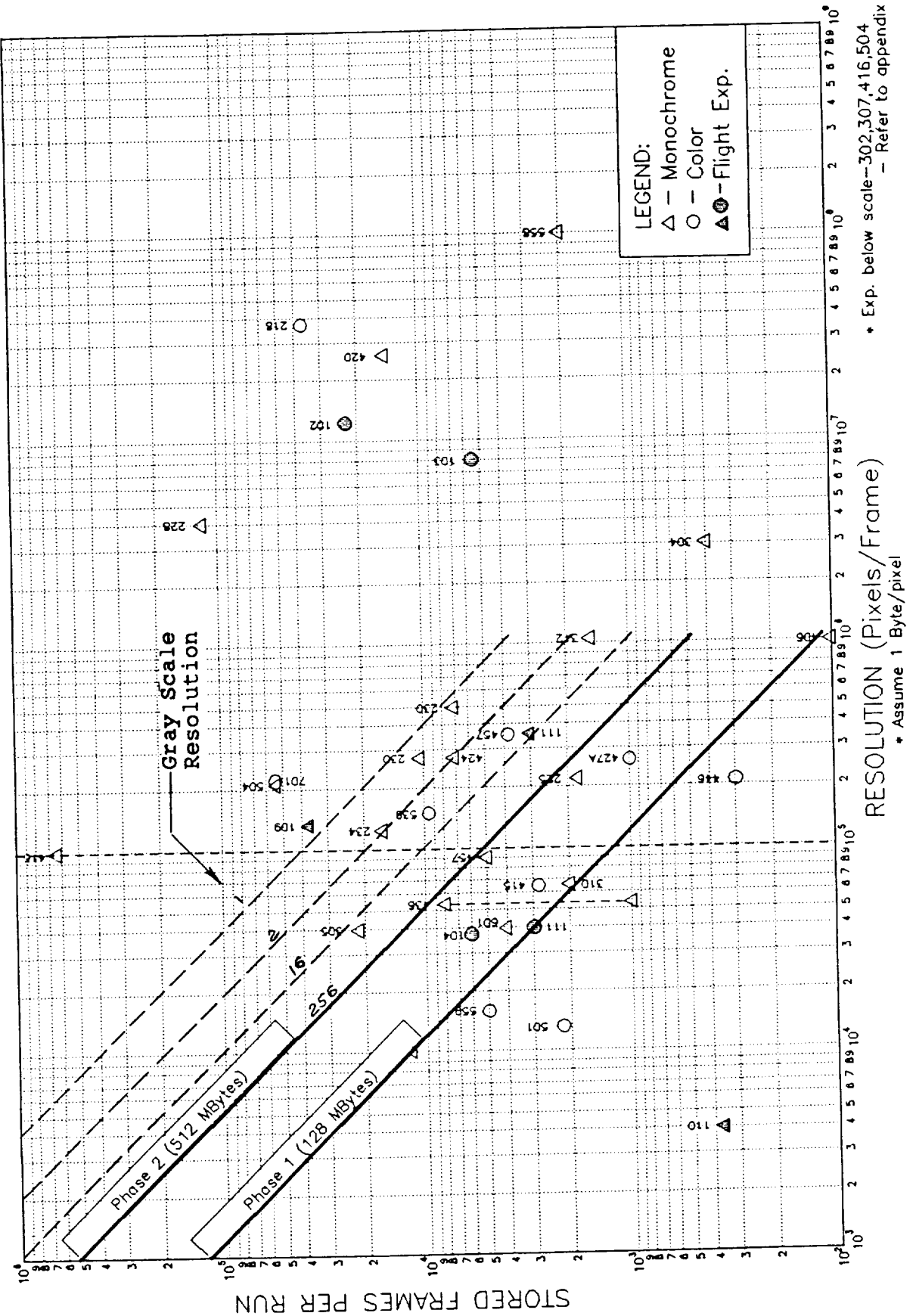


Figure 15

Near-Term System Performance  
Data Storage Capacity vs User Requirements  
Mode: Continuous Tape Record

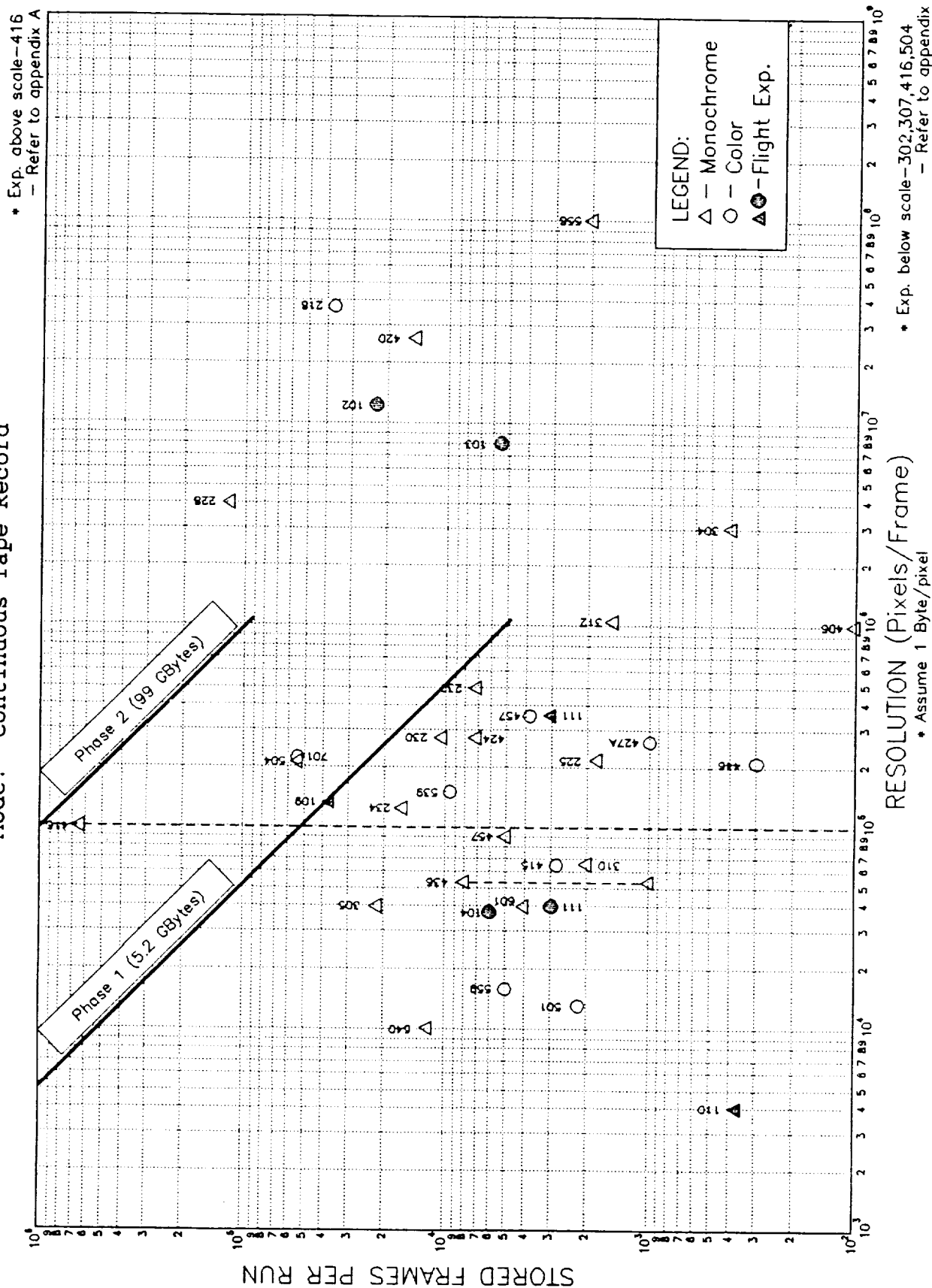


Figure 16

Image Area Occupied by Sync  
and Ancillary Data

Example Shown: 64 x 64 pixels, 1 bit/pixel

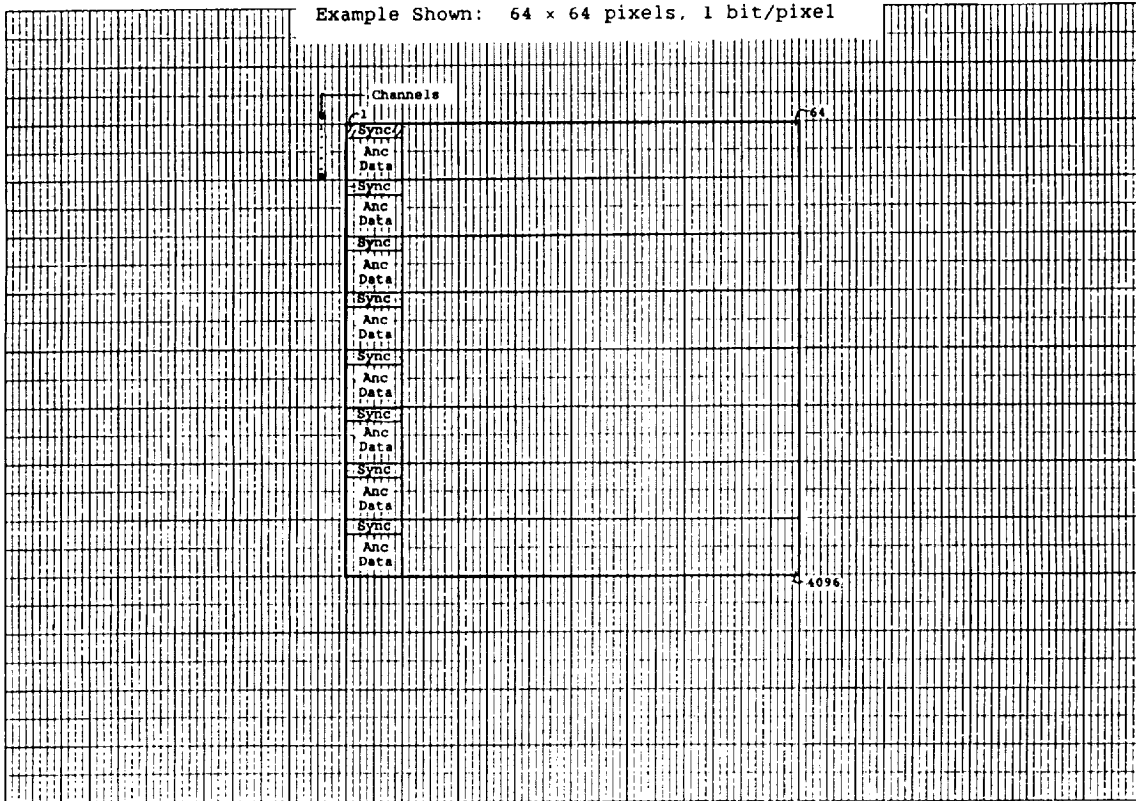


Figure 17

Image Area Occupied by Sync  
and Ancillary Data

Example Shown: 128 x 128 pixels, 1 bit/pixel

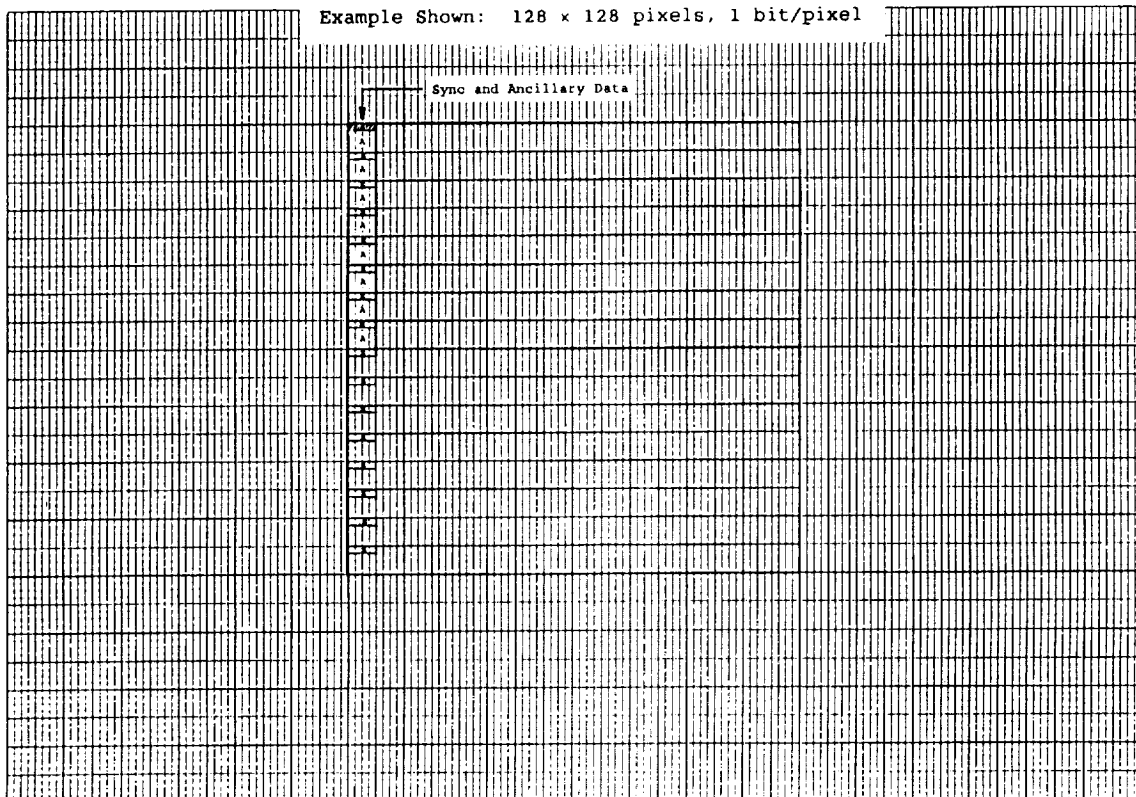


Figure 18

Dynamic RAM Configuration  
(Near-Term Phase II)

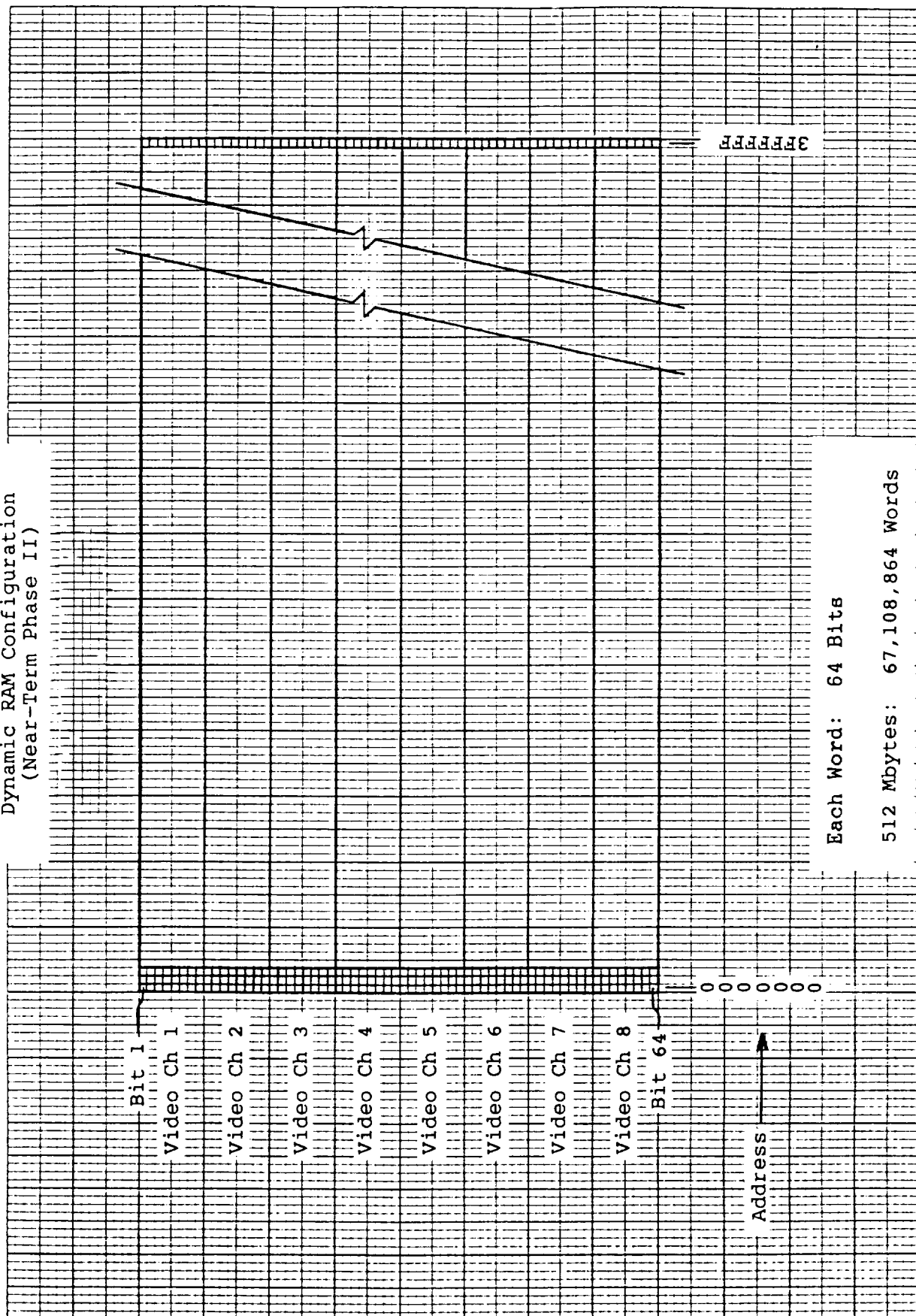


Figure 19

Proposed HHVT Data Format  
 8 Channel Parallel Scan  
 (Near-Term Phase II)  
 Example Shown:  $64 \times 64$  pixels, 1 bit/pixel

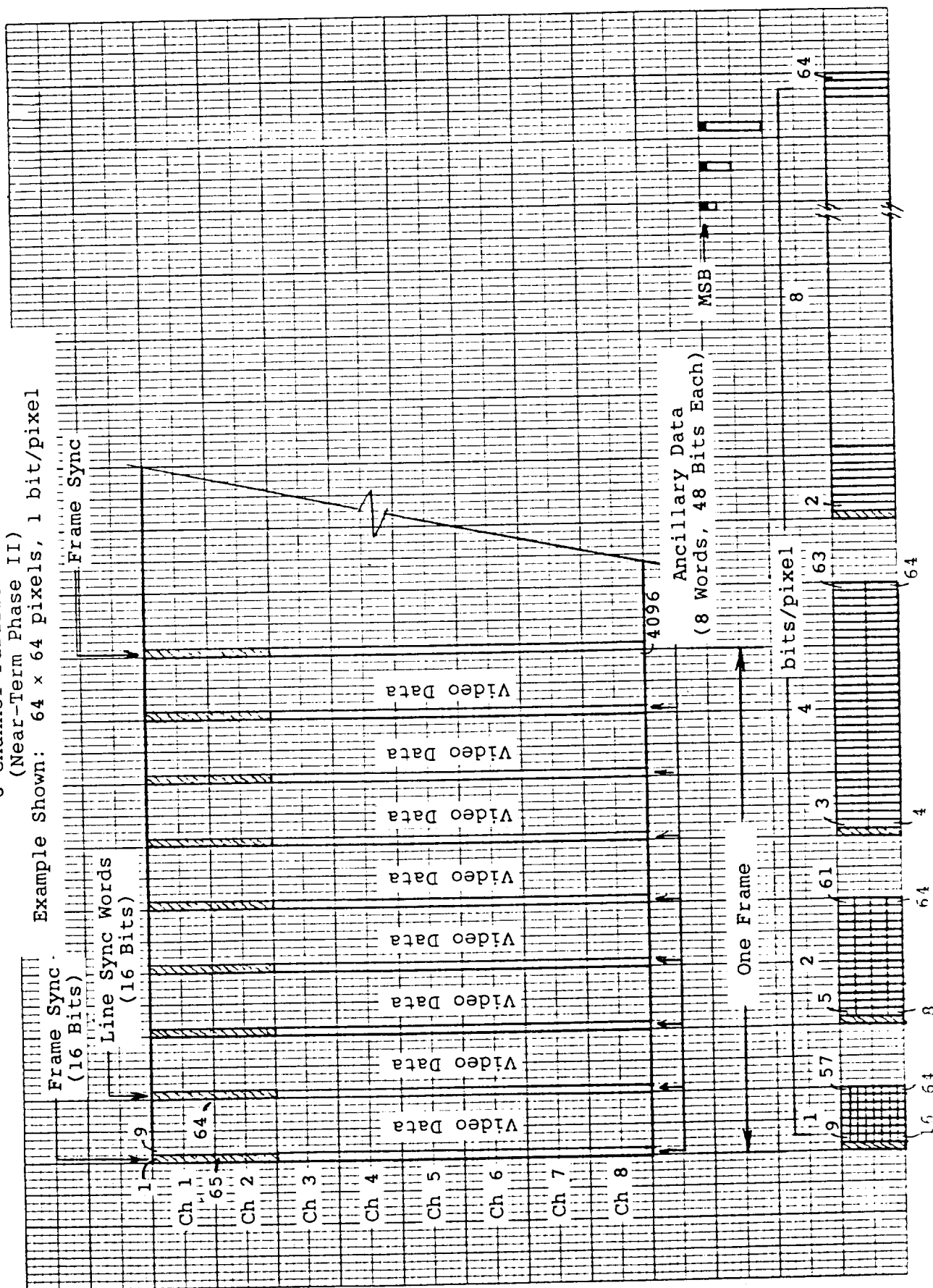
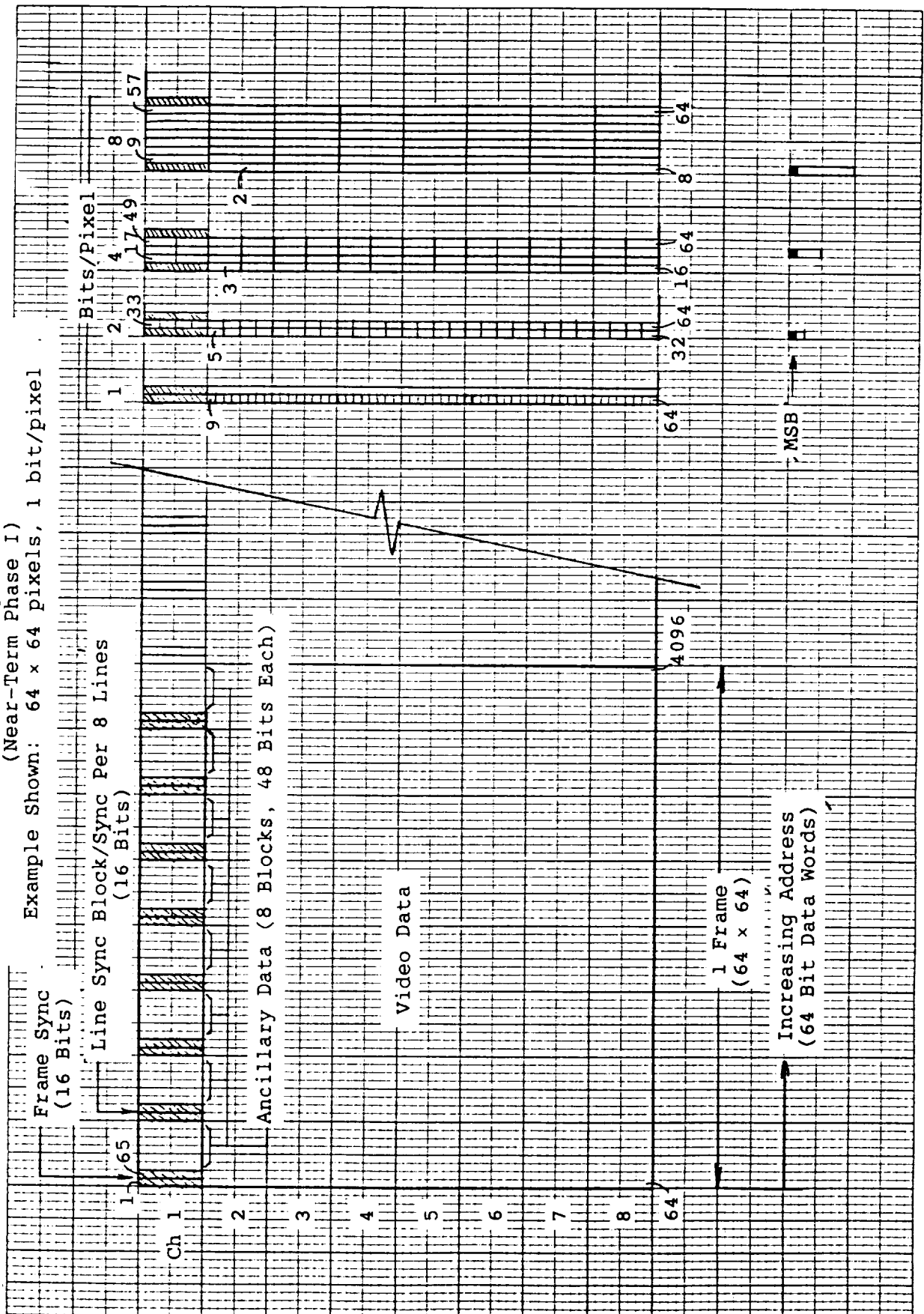


Figure 20

Proposed HHVT Data Format  
Single Channel Progressive Scan  
(Near-Term Phase I)

Example Shown: 64 x 64 pixels, 1 bit/pixel



## COMMENTS FROM THE USERS WORKING GROUP

The following summarizes the comments that were made by the participants in the Users Working Group meeting in response to questions posed by the leader of the discussion, Jack A. Salzman, Chief of NASA Lewis Microgravity Science and Technology Branch.

When asked whether the High Resolution, High Frame Rate Video Technology (HHVT) project appeared to have a realistic assessment of the users' requirements, the consensus of the participants in the Users Working Group was that it did not. The requirements for color imaging and resolution were ill defined. The scientific imaging needs of the experimenters were not requested so much as were the engineering requirements for the proposed HHVT system. Information on the specific part of the spectrum of interest to the user was not requested. The questionnaire should have asked the users whether they needed more than two cameras for their experiments, if they needed magnification of the subject, and the size of the subject. Whoever wrote the questionnaire erroneously assumed that experimenters understand how video technology actually operates. Due to the use of technical terminology, the experimenters could not understand some of the questions on the HHVT users' questionnaire.

In order to complete NASA's survey of users' requirements, the requirements for scientific fields not yet represented in the HHVT users' requirements database should be defined. The majority of the experimenters who responded to the questionnaire have experiments that are in the conceptual design phase already.

One participant recommended that NASA engage a contractor to handle the marketing role of interacting between the users and the design engineers. Several participants commented that the technical experts would leave the HHVT Users Workshop without knowing the real needs of the users. The HHVT project team was advised to go out on a one-to-one basis with the experimenters and solicit information on specific experiments. An effort should be made to identify both the minimum requirements of the users as well as their ultimate requirements for imaging their experiments. This type of one-to-one information exchange would be far more productive than conducting additional surveys. NASA should also establish some forum for acquiring information on users' requirements and then making it accessible to the interested public. NASA should also give high priority to developing video technology to satisfy the requirements of users that cannot be met by existing technology.

When asked whether they thought the correct approach was being applied to address users' needs, the participants answered affirmatively, but they cautioned that the questions in the survey did not fully cover the users' imaging needs. There should be far more communication between the users and the design engineers.

One participant expressed the opinion that it is wasteful for NASA to spend a few million on HHVT development when the video industry is spending far more on research and technology. He thinks NASA could better assist experimenters by developing a system capable of spectral radiance measurements onboard the Space Shuttle. Another participant disagreed and noted that NASA is not constrained by limited bandwidths as is industry. High resolution, high frame

rate video technology for space applications is very much needed, and academia and industry expect NASA to be the agency pursuing this area of technology development. It is unlikely that industry would invest in this area of research and development independently. The commercial demand is almost nonexistent. One person asked whether NASA actually intends to fund the development of imaging chips considering the high cost involved.

The purpose of the near-term HHVT system is to function as a breadboard to test the technology. The participants were asked whether they thought developing the breadboard was sensible. One participant commented that the breadboard method is the only logical approach for this type of technology advancement. But he cautioned the HHVT project team not to regard the breadboard as a flight prototype. Another participant observed that no one system could meet all of the users' requirements. A more flexible type of system with interchangeable components will be needed. NASA will have a good system when NASA builds one that satisfies 80 percent of the users' requirements, after those requirements have been better defined.

To some participants the idea of using a plumbicon imager for the Phase I HHVT system seemed inappropriate. They advised against using tube cameras in a flight prototype of the HHVT system. They recommended that more emphasis be placed on the development of a solid state sensor and more thought given to fast CCD readout. The near-term HHVT system should have at least three different types of cameras for ultraviolet, infrared, and visible light imaging. The rest of the system must be designed to accommodate all of these cameras, one at a time. According to the participants, there is no requirement identified for true color. False color imaging, achievable with the use of trim filters, will suffice. But there is a need for the HHVT system to enable spectral radiance measurements.

The participants were asked whether a data compression capability should be an integral part of the HHVT system. For some, data compression will be user and image dependent, and should be implemented by the user as he sees fit. It should not be an integral part of the HHVT system. Other participants disagreed, but they pointed out that users would want to be able to control the application of compression to their image data. One person observed that data compression is a TDRSS-driven problem. Whenever the shortage of downlink channels is alleviated, the need for data compression will dissipate. The HHVT project team was advised to solicit information on the planned in-space operations for each experiment, so as to be able to assess whether real-time downlink for a given experiment is a necessity. The participants thought the cyclic buffering capability of the HHVT system would be useful.

When asked what they thought would happen if the HHVT program were discontinued, the participants expressed the opinion that the users would all build their own video systems tailored to their specific needs. Then someone, somewhere along the way, would come up with the idea of building one system having all the capabilities of the individual video systems. The participants applauded NASA for initiating this High Resolution, High Frame Rate Video Technology development project and encouraged the project team to continue with the development of the near-term HHVT systems as breadboards.



## COMMENTS FROM THE TECHNICAL EXPERTS WORKING GROUP

The following summarizes the comments that were made by the participants in the Technical Experts Working Group meeting. James A. Burkhart, Chief of NASA Lewis Instrumentation and Data Systems Branch, led the discussion.

One of the technical experts advised the High Resolution, High Frame Rate Video Technology development project team to consider the signal-to-noise ratio problems associated with the use of image intensifiers. Twenty electrons per pixel exposure is almost worthless for low contrast images. A solid state imager is a better front end than a gated intensifier because it has a higher quantum efficiency, lower noise, exposure gating, better MTF, better response uniformity, no signal lag, and much higher in-scene dynamic range.

Another participant questioned the luminosity of the phenomena being observed in some of the experiments. He wondered whether the users understood the technical meaning of "16 gray levels," because "16 gray levels" implies a very high dynamic range, on the order of 1000 to 1. The human eye can only distinguish 16 gray levels. Often six or seven gray levels is sufficient for an observer to interpret an image, provided the image has high contrast. The HHVT project team was advised to better define requirements given on future user surveys. Probably less than 10 percent of the users who responded to the HHVT users' requirements questionnaire are video equipment experts. Terms such as "lumens" would not be familiar to them. In defining the requirements for resolution, "ISO" is not the correct figure of merit to use. Overall, the HHVT users' survey did not provide enough information for sensor manufacturers to understand the imaging requirements of the experimenters. For each experiment they would need to know the source of light, frame exposure time, frame rate, dynamic range requirement, and spectral distribution. Knowing how an experimenter views his final images, and whether those images are high or low in contrast would also be helpful. The technical experts further advised the HHVT project team to solicit information on the type of optical system and film used by the experimenter in his laboratory. It may be necessary for each user to determine his scientific imaging requirements quantitatively, instead of just qualitatively. It remains NASA's responsibility to translate the scientific requirements presented by the users into engineering requirements for the design of the near-term HHVT system. The experts also recommended that the HHVT project team follow up on the responses they receive from users on future surveys. There should be more interaction between the system developers and the users.

With regard to data compression, the experts advised NASA to address this problem as an end-to-end issue. Also NASA should consider the possibility of compressing data prior to storing it in the high speed memory. There are commercial systems that could be used.

In closing, the observation was made that the microgravity science community has set forth requirements to stimulate video technology development, and these requirements are for a general purpose system. In trying to satisfy all the users, the HHVT project team may not be able to satisfy any of them. The HHVT project team should periodically remind the users that the near-term HHVT system is being designed to satisfy a constrained set of their stated requirements.

## FINDINGS AND RECOMMENDATIONS

After the users and the technical experts had separately discussed the results of the HHVT users' requirements survey, the proposed near-term HHVT system, and the future course of the HHVT development project, both groups reconvened to share their findings and recommendations. The following list of findings was mutually agreed upon by the users and the technical experts:

(1) The HHVT project does not have a realistic assessment of users' requirements.

(a) More information is required on each specific experiment.

(b) The requirements should be expressed as scientific requirements rather than as engineering requirements.

(2) The Phase I system should be pursued as a breadboard system, but not as an operational (flight prototype) system.

(3) The Phase I and Phase II HHVT systems should be designed to accept a variety of modular subsystems as the technology advances.

(4) True color is not a requirement, but the ability to make spectral radiance measurements is. This will require a 12 bit system (an 8 bit system is currently planned for both the Phase I and Phase II systems).

(5) The "burst mode" is highly desirable.

(6) Onboard viewing is highly desirable.

(7) It is premature to decide whether subframing is preferable to the use of integrated pixels. Therefore, both methods should be developed.

(8) Edge definition processing should be accorded a high priority.

The following list of recommendations was mutually agreeable to the users and the technical experts:

(1) Each of the investigators should be contacted on an individual basis in order to obtain more detailed information on the scientific imaging requirements.

(2) Once the engineering requirements for the HHVT systems are defined, the HHVT project team should follow up with the investigators to discuss possible tradeoffs.

(3) In proceeding with the Phase I breadboard system, the HHVT project team should make use of their updated survey requirements. Also, they should keep the system flexible and involve the user in system testing and evaluation.

(4) The HHVT project team should concentrate on developing areas of video technology that industry is not developing. One example is flexible ways of compressing data.

## ABBREVIATIONS AND ACRONYMS

ATD	advanced technology development
ATDRSS	Advanced Tracking Data Relay Satellite System
BER	bit error rate
bit	binary digit
byte	eight bits
CCD	charge coupled device
CID	charge injection drive
G/T	gain-to-noise temperature ratio
Gbit	Gigabit
GSTDN	Ground Spacecraft Tracking and Data Network
IDS	intensity dependent spread
MCP	multichannel plate
MOS	metal oxide semiconductor
MTF	modulation transfer function
MUX	multiplexer
NPDT	nonparallel (magnetic) disk transfer
PDT	parallel (magnetic) disk transfer
pels	picture elements
pixels	picture elements
RAM	random access memory
RGB	red, green, blue
SBIR	Small Business Innovative Research
SCSI	small computer system interface
SFR	spatial frequency response
TDRSS	Tracking Data Relay Satellite System
VLSI	very large scale integration
YIQ	luminance (Y) and chrominance (I,Q) signals

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16. Abstract  This publication is a compilation of papers and working group summaries presented at the High Resolution, High Frame Rate Video Workshop held at NASA Lewis Research Center, Cleveland, Ohio, May 11-12, 1988. Presentations were made by NASA engineers engaged in the development of a high resolution, high frame rate video system intended for future use on the Space Shuttle and Space Station Freedom. The papers covered the following topics:  <ul style="list-style-type: none"> <li>(1) State of the art in video system performance</li> <li>(2) Development plan for the high resolution high frame rate video system</li> <li>(3) Advanced technology development for image gathering, coding and processing</li> <li>(4) Data compression applied to high resolution, high frame rate video</li> <li>(5) Data transmission networks</li> <li>(6) Results of the users' requirements survey conducted by NASA</li> </ul> This workshop was held for the dual purpose of (1) allowing potential scientific users to assess the utility of the proposed system for monitoring microgravity science experiments and (2) letting technical experts from industry recommend improvements to the proposed near-term high resolution, high frame rate video system.					
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